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Allocating Yellowfin Tuna Between the Multispecies Purse Seine and Longline Fleets

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Abstract *Yellowfin tuna in the western Pacific are harvested as juveniles by purse seiners and as adults by longliners. The study presents estimates of the multi-species harvest technology of these two types of vessel operating in Papua New Guinea's Exclusive Economic Zone. The results, together with price and cost information and estimates of the impact of the purse seine catch on the catch rates of longline vessels are used to perform a benefit/cost analysis of a reallocation of juvenile yellowfin through a one percent decline in purse seine harvest in PNG's EEZ. The marginal benefit of investment in the yellowfin stock is found to exceed that of marginal cost, suggesting that there may be an economic case for a reallocation.*

Keywords Resource sharing, multispecies fisheries, yellowfin tuna

Introduction

In the western Pacific, yellowfin tuna are harvested as juveniles by purse seiners and as adults by longliners. Countries with extensive Exclusive Economic Zones (EEZs) in the region, such as Papua New Guinea (PNG), attempt to control access of foreign vessels so as to maximize the net present value of their tuna fisheries, thereby maximizing the potential return to the host country. While extensive tagging studies are underway (South Pacific Commission (1990)) there is currently insufficient information available about yellowfin stocks to conduct a bioeconomic analysis which would indicate the net present value maximizing harvesting levels by the two gear types. Instead, the present study addresses the question of whether a reallocation of the yellowfin stock, in the form of a one percent decline in the purse seine harvest from its current level in PNG, would increase the net present value of the country's tuna fisheries under the current management regime.

To assess the economic value of a reallocation of PNG's yellowfin stock, the marginal benefit to the longline fishery and marginal cost to the purse seine fishery, in net present value terms, are estimated on the assumption that the consequent changes in harvest are not large enough to affect world tuna prices: the purse seine catch in PNG's EEZ constitutes around 10% of that of the South

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Pacific Commission Statistical Region, and the longline catch less than one percent; the South Pacific Commission Statistical Region accounts for around one-third of total world tuna catch. The analysis takes into account the multi-species nature of the purse seine and longline fisheries: in addition to juvenile yellowfin, the purse seine fishery harvests skipjack, and the longline fishery harvests bigeye, albacore, billfish and swordfish. If the estimate of marginal benefit exceeds that of marginal cost there is an economic case for curtailing the purse seine fleet's juvenile yellowfin catch to some extent. In the absence of detailed stock information it is not possible to estimate an optimal percentage reduction of the purse seine catch.

The second section of the paper presents some background information about the western Pacific tuna fisheries and about the yellowfin fishery in particular. In the third the interaction between the purse seine and longline fleets is considered. This section of the paper is based on work by Medley (1989, 1991). Medley's results are used to compute the elasticity of response of longline yellowfin catch per hook to a decline in the purse seine catch of juvenile yellowfin. The fourth section describes the multi-species fishery models and the way in which they are used to estimate the marginal benefits and costs of conserving juvenile yellowfin. A dual revenue function approach is used to describe the behaviour of tuna fleets, from which certain characteristics of the technology and mode of operation of vessels can be deduced. The fifth and sixth sections report the estimation of the multi-species production technology for the US purse seine and Japanese longline fisheries in PNG. Estimates of the various elasticities derived from the fishery models, and used in the benefit-cost calculations, are reported. In the seventh section the results of the benefit-cost analysis are presented, and the last section summarizes the conclusions of the study.

Background

Four major tuna species are harvested by five main gear types in the western Pacific. Table 1 reports average catches by gear type for the period 1987–91 in the South Pacific Commission statistical region. The data in Table 1 are based on the fishing activities of 18 nations, with Indonesia, Japan, Korea, Philippines, Taiwan

Table 1
Average Catch of Major Tuna Species by Gear Type in the SPC Statistical Area, 1987–91

Gear Type	Species (mt)			
	Albacore	Bigeye	Skipjack	Yellowfin
Purse seine	—	—	452,675	145,491
Longline	16,932	36,224	—	35,268
Pole and Line	—	—	117,981	3,847
Driftnet	7,278	—	—	—
Troll	5,955	—	—	—

Source: South Pacific Commission (1992). The average are based on calendar years for purse seine, longline, and pole and line vessels, and fishing seasons for driftnet and trolling vessels. A proportion of the reported yellowfin catch of purse seines consists of juvenile bigeye.

and the United States being the major participants. Three significant gear interactions appear to have been taking place amongst these fisheries: the interaction between the driftnet/troll and longline fisheries through the albacore stock; the interaction between the purse seine and pole-and-line fishery through the skipjack stock; and the interaction between the purse seine and longline fisheries through the yellowfin stock. Measures have been taken by Pacific Island nations to restrict driftnetting for albacore, and the pole-and line fishery is being phased out by distant water fishing nations as uneconomic. The present paper deals with the allocation of the yellowfin stock between the purse seine and longline fisheries.

The purse seine fishery catches juvenile yellowfin which are approximately 1 year old and average 5 kg, whereas the longline fishery catches adults which are about 2.5 years of age and average 27 kg in weight. The longline catch supplies the sashimi market whereas the purse seine catch is canned. The unit value of the longline yellowfin catch is 2.6[1] times that of the purse seine catch. In determining the appropriate distribution of the yellowfin catch between the two gear types the following factors need to be taken into account: the delay between the escapement of juvenile yellowfin from the purse seine fishery and their eventual recruitment to the adult stock; the relatively high natural mortality rates for yellowfin in the first two to three years of life; the larger size and higher unit value of the longline harvest; and the relative catch rates and harvesting costs of the multi-species purse seine and longline fleets. Since, at current levels of exploitation, recruitment of yellowfin to the purse seine fishery can be considered to be independent of the size of the adult yellowfin stock, it can be assumed that changes in the level of the longline catch do not affect purse seine catches.

There is insufficient information available about PNG's tuna stocks to determine an optimal harvesting plan. Instead, estimates reported in this paper determine whether at recent harvest levels the net present value benefit to the longline fishery of a small reduction in the purse seine yellowfin catch exceeds the net present value cost to the purse seine fishery. Since both fisheries exploit more than one species, with the possibility of substitution or complementarity between species, the benefit and cost estimates presented in this paper are derived from estimated models of the multi-species production technologies of the two fisheries. While there are many nationalities involved, the Japanese longline fleet and the United States purse seine fleet are the largest in terms of the total catch by weight of their respective gear types. The analysis of benefits and costs is based on the operations of those fleets in PNG's EEZ during the 1980's.

The Purse Seine-Longline Yellowfin Interaction

The Interaction Parameters:

The study takes as a starting point a relationship suggested by Medley (1989, 1991) between longline yellowfin catch per hook and the purse seine yellowfin harvest:

$$H(h_{0,t}) = H(0)e^{\sum_{t=t1}^{\infty}(-q_A)h_0e^{-mt}} \tag{1}$$

[1] This is an average on a monthly basis for the years 1984–85 for the Port of Yaizu.

where h_0 is the level of the purse seine yellowfin harvest in a given month, $H(0)$ is the longline yellowfin catch rate in the absence of purse seining, t_1 is the delay in months between escapement of yellowfin from the purse seine fishery and recruitment to the longline fishery, m is an attrition parameter applied to the yellowfin stock, q_A is the interaction parameter, and $H(h_{0,t})$ is the longline catch rate t months after the initial purse seine catch. The relationship is derived from a model which assumes that longline catch per hook can be described by a Poisson distribution. As explained below, this relationship can be used to calculate elasticities describing the short- and long-term response of longline yellowfin catch per hook to changes in the level of purse seine harvest.

Medley's results are derived from a time series analysis of records of monthly catches of yellowfin by longliners and purse seiners for the period 1978–89 in the sub-region 10°N–20°S and 125°E–175°E of the SPC data base. For the purpose of the analysis, each 10° square is treated as a separate unit. The parameter t_1 was set at 18 months on the basis of catch by age data which indicated that the modal ages of the catches of purse seine and longline caught yellowfin were 1 and 2.5 years respectively. The parameter m, which allows for natural mortality and out-migration from the 10° square, was set at 0.133 per month, which is twice the assumed natural mortality rate. The interaction parameter is estimated using a Poisson regression, in which the dependent variable is number of fish caught per thousand longline hooks fished, with a correction for first-order autocorrelation. Further details are reported in the cited papers.

Medley's analysis assumes that the observed decline in longline yellowfin catch rates is entirely due to purse seining. He acknowledges that his estimate of the value of the interaction parameter is a maximum estimate. The present study calculates the marginal benefits and costs, in net present value terms, of yellowfin conservation on the basis of Medley's estimate and provides additional calculations based on lower values of the interaction parameter as a sensitivity analysis.

Interaction Elasticities:

If juvenile yellowfin harvests in the purse seine fishery are reduced, it is anticipated that there will be an increase in yellowfin catchability in the longline fishery. The present study considers the effect of a permanent reduction in the purse seine yellowfin harvest. Consider the yellowfin cohort which is exposed to purse seining at time zero. From Equation (1), the percentage change in the longline catch per hook in month t from that initial cohort in response to a one percent change in the purse seine harvest in month zero is given by:

$$\frac{\partial H(h_{0,t})}{\partial h_0} \cdot \frac{h_0}{H(h_{0,t})} = -q_A e^{-mt} h_0, \qquad t \geqslant t_1. \tag{2}$$

The percentage change in the yellowfin longline catch per hook in month T as a result of a sustained one percent change in the monthly purse seine yellowfin catch commencing in month zero is given by:

$$\epsilon(h_{0,T}) = \sum_{t=t_1}^{T} -q_A e^{-mt} h_0 \tag{3}$$

which, when the summation is performed, can be expressed as:

$$\epsilon(h_{0,T}) = -q_A h_0 e^{-mt_1}(1 - e^{-m(T-t_1+1)})/(1 - e^{-m}) \tag{4}$$

Assuming the reduction in purse seine yellowfin harvest is permanent, then the limit as $T \to \infty$ of $\epsilon(h_{0,T})$ is given by

$$\epsilon(h_0) = -q_A h_0 e^{-mt_1}/(1 - e^{-m}) \tag{5}$$

which is the long-run equilibrium steady-state percentage response of yellowfin catch per unit effort in the longline fishery to a sustained one percent change in the purse seine yellowfin catch. Since $\epsilon_{h_{(0)}} < 0$, a one percent decline in the purse seine yellowfin catch will result in an increase in catch per hook in the longline fishery.

The above elasticity estimates, $\epsilon_{h_{(0,T)}}$ and $\epsilon_{h_{(0)}}$, describe the percentage increase in the number of yellowfin caught per hook in the longline fishery. Since the multi-species production models below are based on monthly harvests measured by weight, the elasticities need to be adjusted by a factor reflecting the relative weights of adult and juvenile yellowfin, W_A and W_J respectively (see Sibert (1987)).

The following values of the variables and parameters, derived, with the exception of W_A and W_J, from Medley (1991), are used to calculate the elasticities:

q_A: 0.000003805 (standard error = 0.000000407)
m: 0.133
t_1: 18 months
h_0: 114,000 fish per month
W_A: 26.5 kg.
W_J: 5 kg.

The computed value of the elasticity $\epsilon_{h_{(0)}}$ is -0.32 in terms of numbers and -1.68 in terms of weight of fish. The latter figure indicates that a sustained one percentage decline in the weight of the purse seine yellowfin harvest would eventually result in a 1.68% increase in the weight of yellowfin caught per hook in the longline fishery. In addition to estimating the marginal benefits and marginal costs of conservation for $\epsilon_{h_{(0)}} = -1.68$, calculations can also be performed for $\epsilon_{h_{(0)}} = -1.00$ and other values to provide a sensitivity analysis.

The Measurement of Benefits and Costs

The Benefit-Cost Model:

The interaction model described above measures the percentage increase in longline yellowfin catch per unit of effort in a 10° square as a result of a one percent decline in the purse seine juvenile yellowfin catch. The area of PNG's EEZ is approximately a 10° square, and, thus the above interaction model can be used in the estimation of the benefits and costs of a reallocation of yellowfin between the purse seine and longline fleets in that Zone during the 1980s. It should be noted that the attrition coefficient, m, in the interaction model incorporates the effect of out-migration on the availability of adult yellowfin to longliners operating in

PNG's EEZ. This means that the increase in the value of the catch of longliners operating in the EEZ understates the total increase in catch of vessels fishing in the region since catch rates may rise in adjacent EEZs through which yellowfin escaping the PNG purse seine fishery may swim.

The study investigates whether, at the levels of exploitation experienced in the 1980's, the marginal benefit of reducing the catch of juvenile yellowfin tuna in PNG's EEZ exceeds the marginal cost. The approach adopted is to estimate the cost, in terms of reduced profit, to a representative purse seine vessel operating in PNG's EEZ of reducing monthly juvenile yellowfin harvest by one percent. That cost is then multiplied by the number of vessels operating in the EEZ under the current management regime to give an estimate of the total monthly cost of the marginal reduction in harvest. Similarly, the benefit, in terms of additional profit, to a representative longliner operating in the Zone of a sustained increase in monthly yellowfin catch per unit effort, resulting from the increase in adult yellowfin stock, is estimated and multiplied by the number of longliners to give an estimate of the total monthly benefit of the marginal investment in the yellowfin stock.

The operations of US purse seiners and Japanese longliners are used to predict the response of the purse seine and longline vessels operating in the EEZ to a one percent decline in purse seine yellowfin catch. The U.S. vessel was chosen as the benchmark for purse seiners as it is generally believed that the advanced technology and operational behaviour of these vessels will dominate future purse seining in the region. Japanese longline vessels were taken as representative of this fishery as all but a negligible amount of longline activity in PNG waters has been by Japanese fleets. Since the purse seine and longline fisheries are multi-species in nature the calculation of per vessel marginal benefits and costs of conservation will be based on estimates of the multi-species production technologies of purse seine and longline vessels. As there were purse seine vessels from the Japanese, U.S., Korean and Taiwanese fleets active in PNG during the 1980s, the total number of purse seine vessels was calculated in U.S. vessel equivalents on the basis of average monthly revenue earning ability.

The Multi-Species Production Model:

Following Squires and Kirkley (1991), it is assumed that in the long-run vessel design, size, gear and equipment and input levels are chosen to maximise profit. It is assumed that in the short-run skippers maximise revenue, given vessel characteristics together with the quantities of the variable inputs such as labour and fuel chosen for the particular fishing trip. Kirkley and Strand (7) describe the revenue maximising behaviour of a price-taking fishing firm based on the generalised Leontief revenue function:

$$R = \sum_i \sum_j \beta_{ij}(P_i P_j)^{1/2} E + \sum_i \alpha_i P_i E^2 \tag{6}$$

where E is some measure of fishing effort per period, and P_i is the price of species i. Symmetry requires that $\beta_{ij} = \beta_{ji}$, $i \neq j$. If the vessel is in long-run equilibrium, as described by Squires and Kirkley (1991), the marginal revenue product of effort will equal the long-run marginal cost of effort, which is assumed to be a constant, *c:*

$$\frac{\partial R}{\partial E} = \sum_i \sum_j \beta_{ij}(P_i P_j)^{1/2} + 2 \sum_i \alpha_i P_i E = c \tag{7}$$

The Per Vessel Cost of Reducing Purse Seine Yellowfin Catch:

Two possible ways of achieving a reduction in purse seine yellowfin catches are considered. First, if purse seine skippers have some control over the species composition of their catch, Papua New Guinea could, in principle, achieve a reduction in juvenile yellowfin catch per vessel by imposing a specific royalty on yellowfin catch. A royalty on yellowfin caught in PNG's EEZ will effectively reduce the price received for this species by purse seiners operating in the Zone. If purse seine skippers are able to adjust the species mix of their catch, they will tend to decrease yellowfin and increase skipjack catches in response to the change in relative species price. Alternatively, if the species mix of the purse seine catch is technically determined (targeting particular species is not possible) then reductions in yellowfin harvest would need to be achieved by a decrease in the overall level of purse seine effort by each vessel, or by a decrease in the total number of purse seine vessels permitted to operate in PNG waters. It will be seen below that the estimate of the marginal cost of reducing the purse seine catch will be significantly lower if purse seiners have the ability to target particular species.

The technology of purse seining can be established by estimating individual species supply functions which are obtained by differentiating Equation (6) with respect to species price, P_i. The input-compensated supply of species i is given by:

$$Q_i = \sum_{j \neq i} \beta_{ij}(P_j/P_i)^{1/2}E + \beta_{ii}E + \alpha_i E^2 \tag{8}$$

A set of equations consisting of a supply equation for each species and the long-run equilibrium condition (7) can be solved for the vessel's equilibrium effort and harvest levels. A constraint on the harvest of species i can be introduced by setting $Q_i = \overline{Q}_i$ and solving for equilibrium effort, the harvests of species other than i, and the constrained price, $\overline{P}_i$, of species i. The difference between the ex-vessel price, P_i, and the constrained price, $\overline{P}_i$, is the unique level of specific royalty, t_i, which, in a static, full information, deterministic framework, corresponds to the binding constraint or quota on vessel harvest (Squires and Kirkley (1991)). The effect of imposing a royalty on species i is to cause an inward shift of the value of the marginal product of effort (VMP) schedule, which is defined in Equation (7). The extent to which the VMP schedule shifts is defined by the elasticity of the VMP schedule with respect to the net price of species i and is given by:

$$\epsilon_{VMP,P_i} = \left[{}^{1/2} \sum_i \sum_j \beta_{ij}(P_iP_j)^{1/2} + 2\alpha_i EP_i\right] \Big/ \left[\sum_i \sum_j \beta_{ij}(P_iP_j)^{1/2} + 2 \sum_i \alpha_i P_i E\right] \tag{9}$$

A decrease in the ex-vessel price received for species *i* as a result of the imposition of a royalty will result in a decrease in the long-run equilibrium level of purse seine effort, determined by Equation (7). The percentage change in the level of effort for a given percentage change in the price received for species *i* is defined by the elasticity of demand for effort with respect to the price of species *i*, which is given by:

$$\epsilon_{E,P_i} = -\left\{ \frac{\sum_i \sum_j \beta_{ij}(P_iP_j)^{1/2}}{\left[c - \sum_i \sum_j \beta_{ij}(P_iP_j)^{1/2}\right]} + \frac{\alpha_i P_i}{\sum_i \alpha_i P_i} \right\} \tag{10}$$

If, on the other hand, purse seine vessels have no control over the species composition of their catch, a reduction in yellowfin catch will require a reduction in the level of effort devoted by each vessel to the fishery, or alternatively a reduction in the number of vessels. If there is diminishing marginal productivity of vessel effort, the former method of achieving the harvest reduction will be less costly than the latter. In this case, the cost per unit of effort is raised, via an access fee levied on fishing effort, and as vessels equate their marginal product of effort with the unit cost of effort, each vessel will decrease its level of effort accordingly. The increase in access fee has the same effect as an increase in the unit cost of effort. The amount by which vessels reduce fishing effort in response to an increase in the per unit cost of effort is given by the elasticity of demand for effort with respect to its unit cost, and is obtained from Equation (7) as:

$$\epsilon_{EC} = c \Big/ \left[c - \sum_i \sum_j \beta_{ij}(P_iP_j)^{1/2}\right] \tag{11}$$

The reduction in vessel effort translates into lower harvests of each species. In general, the percentage fall in per vessel effort which is necessary to secure a one percent fall in the catch of species *i* is given by the product specific scale elasticity which can be calculated from the supply equation as:

$$\epsilon_{Qi,E} = 1 + 1 \Big/ \left\{ 1 + \left[2\sum_i \alpha_i P_i \sum_j \beta_{ij}(P_j/P_i)^{1/2}\right] \Big/ \left[\alpha_i\left(c - \sum_i \sum_j \beta_{ij}(P_iP_j)^{1/2}\right)\right]\right\} \tag{12}$$

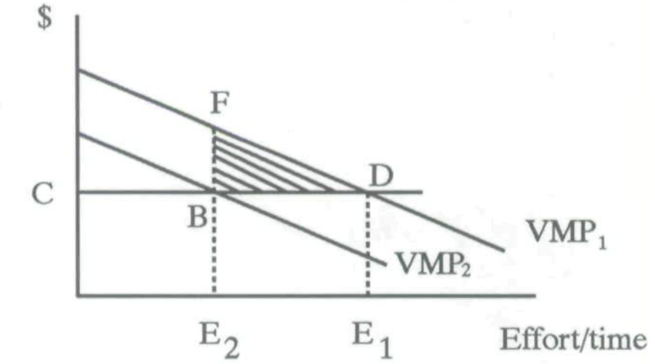
The specific charge, t_e, per unit of effort which is necessary to achieve the per vessel quota, $\overline{Q}_i$ of species *i*, is given by the solution to:

$$\epsilon_{Qi,E} \cdot \epsilon_{E,C}(t_e/c) = (\overline{Q}_i - Q_i)/Q_i \tag{13}$$

where Q_i is the unconstrained per vessel level of supply of species *i*.

The introduction of a royalty or access fee to reduce purse seine yellowfin harvests imposes a cost on purse seine vessels which is partially offset by a gain to PNG. Since the focus of the study is on whether the net present value of the tuna fisheries could be increased by a marginal reduction in juvenile yellowfin catch, rather than on the mechanism or level of fee to be used by Papua New Guinea to collect its share of the value of the fishery, the cost to purse seine vessels of the fee transfer to PNG is ignored in the analysis. The net cost of the reduction in juvenile yellowfin catch is illustrated in Figure 1. If purse seiners can control the species composition of the catch, the royalty on yellowfin harvest has the effect of lowering the private value of the marginal product of effort schedule,

(a) Cost of Policy with a differential royalty on yellowfin (with targeting)



(b) Cost of Policy with increased access fee (without targeting)

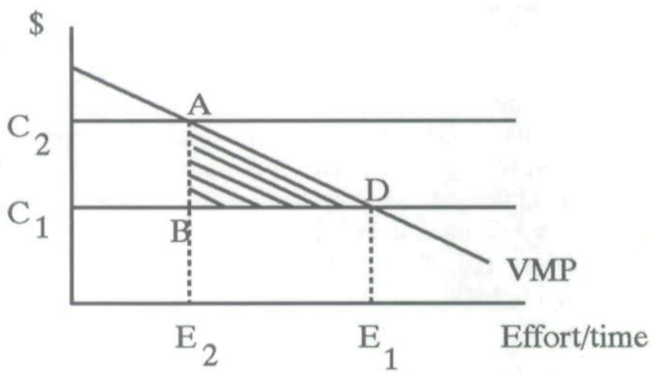


Figure 1. Cost of Protecting Juvenile Yellowfin Under Alternative Assumptions about Technology.

from VMP_1 to VMP_2 in Figure 1(a), and reducing the equilibrium level of effort per vessel. The economic cost of the policy is measured by the shaded area *FBD* which can be expressed as:

$$C_1 = R \cdot \epsilon_{VMP,\, P_i} \cdot \epsilon_{E.P_i} \, (t_i/P_i)^2 \tag{14}$$

where R is per vessel revenue prior to the introduction of the yellowfin royalty, and t_i is the specific royalty which achieves a 1% reduction in juvenile yellowfin catch. If purse seiners are unable to control the proportion of yellowfin they catch then an increase in the access fee will have the same effect as an increase in the cost of effort, reducing equilibrium effort as illustrated in Figure 1(b). The economic cost of the policy is the shaded area *ABD,* which can be expressed as:

$$C_2 = -R \cdot \epsilon_{EC} \, (t_e/c)^2 \tag{15}$$

where t_e is the additional charge per unit of effort which achieves a 1% reduction in juvenile yellowfin catch.

The Per Vessel Benefits of an Increase in Longline Yellowfin Catchability:

The interaction model predicts the percentage rise in longline yellowfin catch per unit effort as a result of a percentage decline in the purse seine yellowfin catch. Using the dual revenue function framework which was applied to modeling purse seine supply, the longline catch of species i per unit of effort is given by:

$$\frac{Q_i}{E} = \sum_{j \neq i} \beta_{ij}(P_j/P_i)^{1/2} + \beta_{ii} + \alpha_i E \tag{16}$$

An increase in the catchability of species i will increase total revenue (R) and shift the marginal revenue function $\partial R/\partial E$, outwards. This is illustrated in Figure 1(a) by a shift from VMP_2 to VMP_1 which causes an increase in the equilibrium per vessel level of effort, from E_2 to E_1. The gain to the average longline vessel is the increase in revenue less the cost of additional effort.

The increase in yellowfin catchability can be modelled by multiplying both sides of Equation (16) by a parameter $\theta \geqslant 1$. Prior to the increase in yellowfin stocks as a result of lower purse seine harvests, $\theta(h_0) = 1$, but the value of the parameter rises subsequently to $\theta(h_1) > 1$ as stocks increase because of the decline in purse seine harvest from h_0 to h_1. The expression $[\theta(h_0) - \theta(h_1)]/\theta(h_0) \approx d\theta/\theta$ is the elasticity of longline catch per unit effort with respect to purse seine catch described in Section 3.2. Each coefficient β_{ij}, $j = 1 \ldots n$, and α_i is multiplied by θ to give the new level of catch per unit effort. Assuming symmetry, total revenue per vessel is then defined as:

$$R = \sum_{j \neq i} \sum_{k \neq i} \beta_{jk}(P_j P_k)^{1/2} E + \sum_{j \neq i} \alpha_j P_j E^2 + \theta \left[\sum_{j} \beta_{ij}(P_i P_j)^{1/2} E + \alpha_i P_i E^2 \right] . \tag{17}$$

The change in per longline vessel revenue as a result of a change in θ can be expressed as:

$$dR = R[\epsilon_{R,\theta} + \epsilon_{R,E} \cdot \epsilon_{E\theta}](d\theta/\theta) \tag{18}$$

where $\epsilon_{R,\theta}$ is the elasticity of per longline vessel revenue with respect to yellowfin catchability:

$$\epsilon_{R,\theta} = 1 \Bigg/ \left[1 + \left(\sum_{j\neq i}\sum_{k\neq i} \beta_{jk}(P_jP_k)^{1/2} + \sum_{j\neq i} \alpha_j P_j E\right) \Bigg/ \left(\sum_j \beta_{ij}(P_jP_i)^{1/2} + \alpha_i P_i E\right)\theta\right]; \tag{19}$$

$\epsilon_{R,E}$ is the elasticity of longline revenue with respect to effort, evaluated at the initial value of $\theta = 1$:

$$\epsilon_{R,E} = \left(\sum_i\sum_j \beta_{ij}(P_iP_j)^{1/2}E + 2\sum_i \alpha_i P_i E^2\right) \Bigg/ \left(\sum_i\sum_j \beta_{ij}(P_iP_j)^{1/2}E + \sum_i \alpha_i P_i E^2\right); \tag{20}$$

and $\epsilon_{E,\theta}$ is the elasticity of equilibrium effort per longline vessel with respect to the catchability parameter:

$$\epsilon_{E,\theta} = -(\theta/E)\left(\sum_j \beta_{ij}(P_iP_j)^{1/2} + \alpha_i P_i E\right) \Bigg/ \left(2\left[\sum_{j\neq i} \alpha_j P_j + \theta\, \alpha_i P_i\right]\right) \tag{21}$$

The change in per longline vessel cost as a results of the increase in effort following the change in catchability is given by:

$$d(cE) = R[(cE/R) \cdot \epsilon_{E,\theta}](d\theta/\theta) \tag{22}$$

Expressions (18)–(22) can be used to calculate the gain in net revenue as a proportion of initial revenue per longline vessel. If, prior to the introduction of policy measures in the purse seine fishery, longline vessels are in long-run equilibrium with respect to effort, Equation (7) can be used to eliminate the effort variable from the elasticity expressions. Having defined the components of a gain to the longline fishery from increased yellowfin catchability in terms of higher per vessel revenues, net of the cost of higher levels of effort, we are now in a position to identify the total net monthly benefit, in terms of increased economic profit, to the longline fleet. The net benefit per vessel in month T, $B(T)$ is given by:

$$B(T) = B \cdot (-\epsilon_{h_{0,T}}) \tag{23}$$

where $B = R\{\epsilon_{R,\theta} + \epsilon_{E,\theta}[\epsilon_{R,E} - (cE/R)]\}/100$, which is the monthly per vessel net benefit of a 1% increase in longline catch per unit effort, and $\epsilon_{h_{0,T}}$ is the percentage change in longline catch per unit effort resulting from the one percent change in monthly purse seine catch: $\epsilon_{h_{0,T}} \equiv d\theta/\theta$.

Estimating the Multi-Species Purse Seine Technology

The Purse Seine Model:

The purse seine fishery of PNG harvests mainly yellowfin and skipjack. The fishery operates throughout the year, with peak activity typically in the months of June–July and December–January. Vessels are free to enter and exit the zone at will provided they hold a current access permit.

When the revenue function described in Equation (6) is expanded to allow for seasonal and annual fluctuations in yellowfin and skipjack stock it is expressed as:

$$R = \sum_i \sum_j \beta_{ij}(P_iP_j)^{1/2}E + \sum_i \alpha_i P_i E^2 + \sum_i \sum_k \delta_{ik} D_k P_i E + \sum_i \sum_r \gamma_{ir} Y_r P_i E \tag{24}$$

where D_k is one of three dummy variables for the quarters Sept–Nov, Dec–Feb and Mar–May and Y_r is one of three dummy variables for the years 1984, 1985, and 1986 included to capture any possible stock availability fluctuations over the period of the analysis.

The supply function $Q_i(P_iE)$ represents the short-run supply behaviour of individual revenue maximizing vessels under the assumptions that they operate independently of one another and cannot individually influence landed fish prices. The vessel-level supply functions, derived similarly to equation (8), from equation (24) are given by:

$$\frac{\partial R}{\partial P_i} = Q_i(P_iE) = \sum_{j \neq i} \beta_{ij}(P_j/P_i)^{1/2}E + \beta_{ii}E + \alpha_i E^2 + \sum_k \delta_{ik} D_k E + \sum_r \gamma_{ir} Y_r E \tag{25}$$

The supply functions (25) for yellowfin and skipjack were estimated for 27 American purse seine vessels operating in PNG, using vessel level catch records for the period 1983–86. Detailed descriptions of the estimation procedure are provided in Campbell and Nicholl (1992b, 1994a). Daily catch records from the South Pacific Commission (SPC) data base were aggregated to give a series of monthly vessel level observations for the fleet. Average monthly ex-vessel prices for the American Samoan port of Pago Pago were used to calculate relative prices. Three price categories for yellowfin (<7.5lbs, 7.51lbs–20lbs, >20lbs) are available for the port of Pago Pago; the mid-range price for yellowfin was used on the basis of Sibert's (1987) observation that the average size of a purse seine caught yellowfin is 5kg. Fishing effort was defined as a composite input related to the capital stock of a vessel. Gross registered tonnage (*GRT*) is used as a proxy for capital stock and is adjusted by a factor to reflect the intensity with which capital stock has been used in any month. Fishing effort per month for a given vessel is measured as $E = GRT \times$ number of sets $\times$ an arbitrary scaling factor of 0.1 to reduce the effort variable to a dimension similar to that of the other variables in the regression.

In some instances vessels record zero catches of both or either of yellowfin or skipjack. Where a vessel reported zero catch for both species in a calendar month, that observation was dropped from the sample (43 of 174 observations) on the grounds that the vessel may have been in transit through the EEZ or engaged in maintenance and repair rather than actively fishing. All the remaining monthly vessel level observations were pooled to estimate the supply functions. Estimating the supply functions where catch, the dependent variable, is zero for one of the species presents a limited dependent variable problem (see Kirkley and Strand (1988)). In order to overcome this statistical problem, zero catches of either species (six observations in each case) were assigned the arbitrarily small value of 0.1 tonnes. The model was also run with the zero catch observations and there was found to be virtually no change to the results.

Estimation of the Purse Seine Model:

The input-compensated supply functions (25) were initially estimated separately by ordinary least squares and tested for heteroskedasticity. Prior expectation was that heteroskedasticity would be introduced via the square of the composite input variable E^2 (see Squires and Kirkley (1991)). Heteroskedasticity of the form discussed by Parks (1970) was found in three of the four supply functions.[2] It was therefore decided to divide the supply functions through by effort (E) and yellowfin and skipjack supply per unit effort equations were then estimated using Zellner's seemingly unrelated regression method and iterating to convergence. The structural form of the supply functions suggested in (25) was tested for symmetry, restricting the coefficients on the quarterly and yearly dummy variables to zero (both sequentially and as a group), and for input-output separable technology. These tests were carried out using a likelihood ratio procedure in which the test statistic $-2[\ln \mathcal{L}_R - \ln \mathcal{L}_U]$, is χ^2 distributed. These results of these tests are reported in Table 2. They indicate that symmetry and restrictions to exclude the quarterly and yearly dummy variables, cannot be rejected, but that restrictions for input-output separability can be rejected.

Tests of regularity conditions were conduced using all estimated coefficients in the preferred model specification. Monotonicity was indicated by the high percentage (92%) of positive values obtained by fitting the revenue function to the data sample. Monte Carlo simulation was used to obtain 1000 sample values for the second derivative of the estimated revenue function with respect to effort, and for the principle minors of the Hessian Matrix, evaluated at mean sample prices. The means of the sample values obtained from the simulation were tested against the null hypothesis of zero. The results of the tests indicated concavity in effort, but convexity in prices could not be accepted as one of the principal minors was significantly negative. To determine whether the absence of convexity in prices

[2] The Breusch-Pagan test for heteroskedasticity was carried out at the 5% level of significance; it has a chi-squared distribution. The critical value with 7 d.f. is $\chi^{2*} = 20.278$, 7: the test statistic for yellowfin supply was $\chi^2 = 53.622$, 7, therefore reject homoskedasticity; and for skipjack supply $\chi^2 = 9.248$, 7, therefore cannot reject homoskedasticity.

Table 2
Tests for Model Structure and Technology

Test	No. of Restrictions	Critical χ^2	Test χ^2	Reject Restriction?
U.S. Fleet:				
Symmetry	1	7.879	0.788	No
Qtr dummies	6	18.548	2.645	No
Yr dummies	4	14.860	5.340	No
Qtr & Yr dummies	10	25.597	6.529	No
Input—Output separability	2	10.597	16.072	Yes

All likelihood ratio tests performed at the 5% level of significance.

was likely to pose problems for the application of the model, the input-compensated own-price elasticities of supply were estimated and found to be positive and significantly different from zero at the 5% level: the estimated elasticities, with standard errors in parentheses, are $\epsilon_{YY} = 5.2517$ (2.7728) and $\epsilon_{SS} = 2.5794$ (1.3619).

The results of the model based on the preferred specification are reported in Table 3 as Model 1. Since in a two-species model the species cannot be complements, the coefficient on the relative price variable, P_S/P_Y, in Model 1 is expected to be either zero or negative. On the basis of a one-tailed t test this coefficient is found to be significantly less than zero at the 5% level. This means that the hypothesis of non-jointness in production can be rejected, and that the species composition of the catch of purse seine vessels can be varied in response to relative price changes (targeting). This result is discussed further in Campbell and Nicholl (1992b, 1994a) where the question of targeting individual species is examined in greater detail. While the hypothesis of targeting is not rejected, the evidence supporting it is marginal and therefore a set of coefficients is also estimated for a model incorporating non-jointness (the restriction $\beta_{ij} = 0$, $i \neq j$). These results are reported as Model 2 in Table 3.

The hypothesis expressed in Equation (7) that the sample vessels were in long-run equilibrium with respect to the level of effort devoted to PNG's EEZ was tested. Using data from a 1985 survey carried out by the U.S. National Marine Fisheries Service, Waugh (1987) estimated the total annual costs, including access fees, of a 1,100 ton purse seine vessel at US$2,674 million, or US$222,815 per month. This figure was used as an estimate of the monthly cost of operating the average size seine vessel of 1,228 tons from the sample of the present study. The average monthly effort, measured as $GRT \times$ number of sets $\times$ 0.1, for the sample was 2,007.2. Based on Waugh's estimate of monthly vessel cost, the average total cost per unit of effort was US$111.01. The results reported for Model 1 indicate that the marginal return to effort for the average U.S. Pacific class purse seine vessel in the sample was $106.27 with a standard error of 18.24. At the 5% level this is not significantly different from Waugh's estimate of unit cost (t − ratio = 0.260). For Model 2 the comparable results are $106.03 with a standard error of 18.23, and a t-ratio of 0.273.

Since the hypothesis that the average vessel in the sample is in long-run equilibrium with respect to the level of effort is supported, Equations (9)–(13) can be used to derive estimates of the values of the elasticities and variables used to

Table 3
Parameter Estimates of U.S. Fleet Supply per Unit Effort Functions

	Yellowfin Supply		Skipjack Supply	
Variable	Estimated Coefficient	T-ratio	Estimated Coefficient	T-ratio
Model 1				
Effort	−0.0002*	−2.9377	−0.0002*	−2.6051
P_S/P_Y	−0.6620@	−1.8923	−0.6620@	−1.8923
Constant	0.7613*	2.2256	0.8790*	2.4491
$\ln \mathcal{L} = 192.880$				
Model 2				
Effort	−0.00002*	−2.6684	−0.00002*	−2.8537
Constant	0.11474*	6.9238	0.20087*	10.117
$\ln \mathcal{L} = 192.385$				

* Significant at the 5% level, two tail test.
@ Significant at the 5% level, one tail test.

estimate the costs of reducing the yellowfin catch (species *i*) by one percent as defined by Equations (14) and (15). For Model 1, upon which the cost estimate C_1 in Equation (14) is based, the elasticity estimates (with standard errors reported in brackets) are: $\epsilon_{VMP,P_Y} = 0.5037$ (0.1476), $\epsilon_{E,P_Y} = 1.4680$ (0.1907), $t_Y/P_Y = 0.0080$ (0.0037). For Model 2, upon which the estimate C_2 in Equation (15) is based, the estimates are: $\epsilon_{E,C} = -0.9663$ (0.1534), and $t_e/c = 0.0104$ (0.0017).

Estimating the Multi-Species Longline Technology

The Longline Model:

Larger, deeper swimming tunas, particularly yellowfin and bigeye, are the basis of the longline fishery in PNG. In addition there are also catches of albacore and to a lesser extent, marlins, sailfish and swordfish, with incidental catches of shark and other species. The fishery has operated year round in the northern regions of the EEZ and almost exclusively with Japanese vessels.

The longline fishery was modelled in an analogous manner to the purse seine fishery. The estimation procedure is described in detail in Campbell and Nicholl (1992c). Once again, a revenue maximising framework was used to describe the short-run behaviour of firms engaged in longlining activities. Vessel-level catch and effort data which covered the activities of Japanese longline vessels in PNG's EEZ for the period 1980–86 were used to estimate supply responses for yellowfin, bigeye, albacore, 'billfish' and swordfish.[3] There were 238 Japanese longline vessels active in PNG waters for the above period, ranging in size from 59 *GRT* to 424 *GRT*. Most vessel records (85%) were for vessels in the size range 50–100 *GRT* (85%). Price data were obtained from the Forum Fisheries Agency data base. These data are average monthly ex-vessel prices for the Japanese port of Yaizu,

[3] Billfish is a composite species category comprised of blue, black and striped marlins and sailfish.

which typically receives over 90% of Japanese distant water fleet tuna catches. The Fisher ideal index method, which is consistent with the full range of substitution possibilities among sub-species (Diewert (1976)), was used to calculate price indices for the 'billfish' category of fish.

Estimation of the Longline Model:

The revenue function of Equation (24) is the proposed model for the longline fleet, with fishing effort, E, defined as the number of hooks per month (in thousands), and the yearly dummy variables, Y_r, representing each of the years 1981–86, where 1980 is the base period. Supply functions with *CPUE* as the dependent variable were estimated using Zellner's SURE method and iterating to convergence. Tests for model structure and technology were carried out using a log likelihood ratio procedure at the 5% level of significance. The results of these tests are reported in Table 4. Symmetry is rejected in the model and, since it is required to ensure that the species composition for a given level of effort is unaffected by the price level, it is imposed in subsequent estimations. All restrictions to exclude the seasonal and yearly dummy variables are rejected as are those restrictions relating to input-output separability.

Tests of regularity conditions were conducted using all estimated coefficients in the preferred model specification, except those of the dummy variables. Monotonicity was indicated by the fact that all values of the revenue function fitted to the data sample are positive. Monte Carlo simulation was used to derive 1000 sample values for the second derivative of the revenue function with respect to effort, and for the principal minors of the Hessian Matrix, evaluated at mean sample prices. The means of the sample values were tested against the null hypothesis of zero. The results supported concavity in effort, but rejected convexity in prices, with one of the principal minors being positive at the 5% level of significance, two being negative, and two not being significantly different from zero. To determine whether the absence of convexity in prices was likely to pose problems for the application of the model, the input-compensated own-price elasticity of supply for each species, evaluated at mean sample prices, was calculated and tested against the zero null hypothesis. The estimated elasticities, with standard errors in parentheses, are: $\epsilon_{YY} = 0.0041$ (0.0304), $\epsilon_{AA} = 2.0889$ (0.3313), $\epsilon_{EE} = -0.0408$ (0.0842), $\epsilon_{BL} = 0.6993$ (0.5995), and $\epsilon_{SW} = 1.1098$ (0.5691).

The results of the supply function estimations are reported in Table 5. Where estimates of relative price coefficients are not significantly different from zero, the

Table 4
Tests for Model Structure and Technology: Longline Fleet

Test	No. of Restrictions	Critical χ^2	Test χ^2	Reject Restriction?
Symmetry	10	18.31	54.6	Yes
Qtr dummies	15	25.00	169.0	Yes
Yr dummies	30	43.77	3121.8	Yes
Qtr & Yr dummies	45	55.76	3321.2	Yes
Input—Output Separability	5	11.07	54.0	Yes

Table 5
Parameter Estimates for Longline Fleet:Dependent Variable is CPUE

Variable	Estimated Coefficient	T-ratio	Variable	Estimated Coefficient	T-ratio
Yellowfin:			Albacore:		
Constant	642.79*	18.772	Constant	121.43*	7.1719
Effort	0.0687	0.2887	Effort	0.0363	0.4755
P_A/P_Y	−57.586*	−3.2095	P_Y/P_A	−57.586*	−3.2095
P_E/P_Y	40.140*	2.2225	P_E/P_A	−33.105*	−2.8808
P_B/P_Y	−1.7226*	−2.1456	P_B/P_A	−0.5928	−0.5777
P_W/P_Y	1.9469	0.6372	P_W/P_A	−4.6451	−1.4106
Season: 2nd Qtr	−101.37*	−7.6906	Season: 2nd Qtr	0.2369	0.0538
3rd Qtr	−35.921*	−2.7510	3rd Qtr	−10.473*	−2.2941
4th Qtr	−44.518*	−3.4631	4th Qtr	8.3210	1.8658
Year: 1981	−218.11*	−14.099	Year: 1981	31.116*	5.5985
1982	−185.45*	−11.666	1982	10.666	1.8233
1983	36.281*	2.2096	1983	51.986*	8.8383
1984	−146.54*	−7.9287	1984	48.713*	6.5455
1985	−121.31*	−6.8391	1985	4.0501	0.6578
1986	−229.71*	−11.475	1986	22.576*	3.0243
Bigeye:			Billfish:		
Constant	116.61*	7.4576	Constant	1.5530	1.9245
Effort	−0.4408*	−6.9861	Effort	−0.0013	−0.6833
P_Y/P_E	40.140*	2.2225	P_Y/P_B	−1.7226*	−2.1456
P_A/P_E	−33.105*	−2.8808	P_A/P_B	−0.5928	−0.5777
P_B/P_E	0.5162	0.9396	P_E/P_B	0.5162	0.9396
P_W/P_E	−3.1966	−1.6176	P_W/P_B	0.4356	0.5627
Season: 2nd Qtr	−2.2532	−0.6010	Season: 2nd Qtr	0.2141	1.8404
3rd Qtr	22.336*	5.6479	3rd Qtr	0.1254	0.9132
4th Qtr	8.7236*	2.2791	4th Qtr	0.0826	0.6499
Bigeye:			Billfish:		
Year: 1981	−60.594*	−13.150	Year: 1981	−0.0137	−0.0765
1982	−48.281*	−10.426	1982	−0.4245*	−2.6313
1983	−15.349*	−3.3817	1983	−0.3685*	−2.2878
1984	−13.766*	−2.5967	1984	−0.2430	−1.1763
1985	1.2879	0.2624	1985	0.6369*	3.6075
1986	−7.0778	−1.2796	1986	0.3705	1.6378
Swordfish:					
Constant	7.0878*	3.0687			
Effort	−0.0027	−0.3495			
P_Y/P_W	1.9469	0.6372			
P_A/P_W	−4.6451	−1.4106			
P_E/P_W	−3.1966	−1.6176			
P_B/P_W	0.4356	0.5627			
Season: 2nd Qtr	0.4131	0.9120			
3rd Qtr	0.0237	0.0455			
4th Qtr	0.5095	1.0430			
Year: 1981	−0.7897	−1.0881			
1982	−1.9036*	−3.0101			
1983	−2.3659*	−3.7751			
1984	−2.4082*	−3.1228			
1985	1.1099	1.6464			
1986	1.8077*	2.1108			

* Indicates significant at the 5% level for two-tail test.

hypothesis of non-jointness in production cannot be rejected; a significantly negative relative price coefficient suggests that the species are substitutes in production, and a significantly positive coefficient suggests complementarity. Of particular interest are the results for yellowfin supply, which suggest that longline vessel skippers can target various species to a certain degree. Albacore and billfish appear to be substitutes in production to yellowfin, while bigeye is a complement to yellowfin. The other significant joint relationship revealed by the estimation is the substitution relationship between albacore and bigeye. These relationships reflect the fact that yellowfin and bigeye tend to be deeper swimming species than albacore and billfish. The coefficients on the dummy variables included to reveal annual fluctuations in stock availability to the fleet indicate that yellowfin *CPUE* was significantly lower in the years 1981, 82, 84, 85 and 86 than in 1980 and higher in 1983.

The equilibrium condition of (7) was also tested for the longline fleet. An estimate of the average monthly total cost of operating a vessel was calculated from costs reported by Campbell and Nicholl (1990, 1992a, 1994b), where Japanese longline vessels are grouped by size. A weighted average monthly per 'vessel' cost was calculated and 4% of the sample mean value of revenue was added to this estimate to represent access fees.[4] Using the sample mean monthly level of effort (32,205 hooks) the average cost per thousand hooks was calculated as ¥448,796. The estimated marginal return per unit of effort is ¥452,770 which is not significantly different from the unit cost estimate (t − ratio = 0.369), indicating that the hypothesis that the long-run equilibrium condition holds cannot be rejected at the 5% level.

Since the hypothesis that the average vessel in the sample is in long-run equilibrium is supported, Equation (7) can be substituted into Equations (19) – (21) for the purposes of calculating the elasticities $\epsilon_{R,\theta}$, $\epsilon_{R,E}$, and $\epsilon_{E,\theta}$, which are used to calculate the proportionate change in per vessel operating profit, gross of royalties or access fees, resulting from the increased availability of the yellowfin stock to the longline fleet. The elasticity estimates (with standard errors in brackets) are: $\epsilon_{R,\theta} = 0.0158$ (0.2866) $\epsilon_{\mathrm{R,E}} = 0.9800$ (0.0111); and $\epsilon_{E,\theta} = 20.167$ (11.212). Given these elasticity estimates, Equations (18) and (22) can be used, together with the information on average monthly vessel revenue and cost, to calculate the monthly net benefit per vessel of a 1% increase in yellowfin catchability.

Calculating Marginal Benefit and Marginal Cost of Reallocation

In this section the monthly benefits and costs of a 1% reduction in the yellowfin catch of each purse seine vessel operating in PNG's EEZ are calculated. These are defined as the values of the estimated changes in the profits, gross of changes in royalties or access fees, of the longline and purse seine fleets. The calculations are based on the average number and average monthly revenues of representative vessels operating during the sample periods.

[4] The weights for the cost of effort based on vessel size are $50 \leqslant GRT \leqslant 100$ (0.761), $100 < GRT \leqslant$ (0.230) and $200 < GRT \leqslant 500$ (0.009) according to the number of observations in the sample. Access fees were calculated at 4% of revenue according to FFA (1986). The average cost per month per vessel is ¥13,858,329 and the sample mean monthly total revenue is ¥14,879,000.

The purse seine fleet during the sample period consisted of a monthly average of 4.7 U.S. vessels, 24.2 Japanese vessels, 3.5 Korean and 2.0 Taiwanese vessels. The U.S. vessels are larger and more modern and have greater catching power than the Japanese. For the sample period 1984–86 the average monthly revenue of the Japanese vessels was 70% of that of the U.S. boats, while it was 73% for Korean vessels and 98% for the Taiwanese vessels. Since the more modern U.S. vessel are used as the representative vessel the purse seine fleet is assumed to consist of 26.2 U.S. type vessels. The longline fleet during the sample period consisted entirely of Japanese vessels, averaging 53 vessels per month over the sample period. Estimates of changes in the profit of Japanese longline vessels are converted from Japanese Yen to U.S. dollars using an average exchange rate for the sample period of 225.5 Yen to the Dollar.

As can be seen from Equations (14), (15) and (23), the estimates of per vessel net marginal cost or benefit of a reallocation are expressed as a percentage of average monthly per vessel revenue. The per vessel benefit and cost estimates are multiplied by the number of vessels in the fleet to give an estimate of the monthly benefit or cost to the fleet in question. These monthly estimates are then converted to present values for the comparison of benefits and costs.

Available data and coefficient estimates from the purse seine and longline models allow a set of monthly benefit and cost estimates to be prepared for each season and year. However, only one estimate based on the predicted average of monthly revenue for the representative vessel, on elasticities evaluated at mean values for the sample periods, and on the basis of the default values of the dummy variables, is reported. The values used in the calculations are summarized in Table 6.

Table 6
Average and Estimated Values Used in the Benefit Cost Calculation

Term	Equation	Value	Standard Error
		(a) Purse Seine Model	
$\epsilon_{VMP,PY}$	(9)	0.50369	0.14763
$\epsilon_{E,PY}$	(10)	1.4680	0.19066
$\epsilon_{E,C}$	(11)	-0.96628	0.15339
$\epsilon_{QY,E}$	(12)	1.0021	0.001002
(t_Y/P_Y)	(8)	0.008032	0.00370
(t_c/c)	(13)	0.01037	0.001654
R/month		\$333,500	
n		26.2	
r		0.002467	
		(b) Longline Model	
$\epsilon_{R,\text{»}}$	(19)	0.0158	0.2866
$\epsilon_{R,E}$	(20)	0.9800	0.0111
$\epsilon_{R,\theta}$	(21)	20.617	11.212
ϵ_{h_0}		-1.68	0.1803
R/month		\$65,984	
n		53	
r		0.002467	

The yellowfin catchability parameter, $\epsilon_{h_{0,T}}$, starts to increase 18 months after the reduction in the purse seine yellowfin catch and thereafter asymptotically approaches the steady state value ϵ_{h_0}. The present value of the benefits of increased catchability is:

$$PV(nB(T)) = \frac{1}{(1+r)^{t_1}} \sum_{T=0}^{\infty} \frac{nB(-\epsilon_{h_{0,T}})}{(1+r)^T} \tag{26}$$

where r is the monthly real rate of interest corresponding to a 3% per annum real rate.

When the summation is performed, Equation (26) can be expressed as:

$$PV(nB(T)) = \frac{1}{(1+r)^{t_1}} nB(-\epsilon_{h_0}) \left[\frac{1}{r} - \frac{e^{m(t_1-1)}}{1 - e^{-m}(1+r)^{-1}} \right] \tag{27}$$

In Equation (27) the term $nB(-\epsilon_{h_0})$ represents the monthly steady state benefit, while the term in square brackets converts the monthly steady state benefit to a present value at time t_1. The adjustment to the perpetual annuity factor, $1/r$, accounts for the fact that the monthly benefit approaches but never reaches the steady state.

The estimate of the monthly cost of the juvenile yellowfin reallocation policy depends upon whether it can be implemented by a differential royalty on the yellowfin catch, or whether an increased access charge per unit of effort will be required to reduce the yellowfin catch indirectly by reducing effort. The present value of the cost of the policy is given by:

$$PV(C_1) = \frac{nC_1}{r} \tag{28}$$

$$PV(C_2) = \frac{nC_2}{r} \tag{29}$$

where C_1 and C_2 are defined in equations (14) and (15) respectively.

When Equation (27) is evaluated using the information reported in Table 6(b), an estimate of $3,576,844 is obtained for the present value to the longline fishery of a one percent decline in the purse seine yellowfin catch. When equations (28) and (29) are evaluated using the information reported in Table 6(a) estimates of $168,953 and $368,035 are obtained for the net present value of the costs to the purse seine fleet of a one percent reduction in juvenile yellowfin catch in the targeting and non-targeting cases respectively. These results suggest that the marginal benefit of a one percent reduction in purse seine juvenile yellowfin catch in PNGs EEZ exceeds the marginal cost on either assumption about the targeting ability of purse seine vessels.

The estimates reported above are point estimates derived from expressions which define marginal benefits and costs. These expressions include the values of observed variables and estimated parameters. It is well recognised that values which are calculated as nonlinear functions of estimated parameters can be subject to relatively large standard errors. The standard errors of the marginal benefit and marginal cost estimates reported above were calculated according to the procedure detailed in the Appendix. The marginal benefit and marginal cost estimates, with standard errors in brackets, are \$3,576,844 (6,228,370), \$168,953 (108,250), and \$368,035 (58,918). It should be noted that, of the parameters of the interaction model reported above, only the interaction parameter, q_A, has been treated as a random variable. This means that the reported standard errors understate the standard error of the marginal benefit estimate.

The point estimates of marginal benefit (MB) and marginal costs (MC_1 and MC_2) can be treated as means of independent samples, since they are derived from the longline and purse seine samples respectively, and the null hypotheses $MB - MC_1 = 0$ and $MB - MC_2 = 0$ can be tested. The test procedure is outlined in the Appendix. The t-statistics for the two hypotheses are 6.169 and 5.705 respectively. These values suggest that accepting the hypothesis that the net marginal benefit of a reallocation of the yellowfin stock is zero (for both the targeting and non-targeting scenarios) involves a high probability of Type II error. Thus it seems probable that there is an economic argument for some degree of reallocation of yellowfin tuna between the two fleets.

It was noted above that the estimate of the interaction parameter should be considered as an upper bound. Lower values of the parameter would reduce the estimate of the marginal benefit of conservation. For example, if the value of the interaction elasticity fell in absolute terms from 1.68 to 1.00, the marginal benefit estimate would fall from around \$3.6m to \$2,129,074. The marginal benefit corresponding to any other value of the interaction elasticity can be obtained by multiplying the latter figure by the absolute value of the elasticity. In the non-targeting case the value of the interaction elasticity would need to be 0.17 in absolute terms in order to reduce the marginal benefit/cost ratio to unity.

Conclusions

The estimates presented in this paper suggest that the economic benefit of a one percent decline in purse seine juvenile yellowfin catch in PNG's EEZ may exceed the cost. If purse seiners can target yellowfin to the extent suggested by the supply analysis of U.S. purse seine activity, the excess of estimated marginal benefit over marginal cost may be substantial. Even in the absence of targeting ability the benefit/cost ratio of a marginal investment in PNG's yellowfin stock could be in the order of 10/1 if the value of the interaction elasticity is as high as indicated by Medley's results. The results of the paper suggest that there may be a *prima facie* case for reducing purse seine harvests of juvenile yellowfin. Because of the sensitivity of the marginal benefit estimates to the results of the interaction model, and because the model does not reveal how far the policy of reallocating the yellowfin stock should be carried, further research, preferably incorporating information on tuna stocks, is required.

The analysis has taken no account of the costs Papua New Guinea would incur in implementing and enforcing a policy of conserving juvenile yellowfin and collecting a share of the increased profits generated by tuna fishing in its EEZ. Furthermore, the results of the study are based on patterns and levels of fishing activity in PNG during the 1980s and may not be directly relevant to the present situation in PNG or in other Zones. If all Pacific Island countries pursued a policy of limiting the catch of juvenile yellowfin, each would benefit through outmigration of adult fish from other Zones. On the other hand, world tuna prices would probably be affected, reducing the benefits of reallocation and increasing the costs. Nevertheless, the estimates suggest that a policy of conserving juvenile yellowfin with the aim of increasing longline catches of adult fish should be considered by PNG and other nations in the Pacific Islands region.

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Appendix:

(i) Standard error calculation:

Standard errors for the marginal cost estimates to the purse seine fleet of restricting juvenile yellowfin harvests by this gear type are provided as part of the output of the SHAZAM package. SHAZAM was used for the estimation procedures of the purse seine and longline supply response models of Sections 3 and 4. Recall that the present value of marginal cost C_i is given by:

$$PV(C_i) = \frac{nC_i}{r}$$

for $i = 1$ (targeting) and 2 (non-targeting); and where n/r is treated as a constant and the standard error of C_i (the random variable component) is a function of the variances and covariances of the estimated parameters from the purse seine targeting and non-targeting models. The standard error of the present value of the marginal cost estimate is therefore calculated as;

$$\sigma_{MC} = \sqrt{\{(n/r)^2[Var(C_i)]\}}.$$

The standard error of the marginal benefit estimate is a function of a parameter estimated outside the longline model, $(-\epsilon_{h_0})$, and was calculated in the following manner. Recall that;

$$PV(nB(T)) = \frac{1}{(1 + r)^{t_1}} nB(-\epsilon_{h_0}) \left[\frac{1}{r} - \frac{e^{m(t_1-1)}}{1 - e^{-m}(1 + r)^{-1}}\right]$$

where all but the monthly steady state benefit $nB(-\epsilon_{h_0})$ can be treated as a constant. Therefore the standard error of the estimate is calculated as;

$$\sigma_{MB} = \{\text{Var}[PV(nB(T))]\}^{1/2}$$

where

$$\{Var[PV(nB(T))]\} = a^2[Var(nB) + Var(-\epsilon_{h_0}) + 2Cov(nB, -\epsilon_{h_0})]$$

and where

$$a = \frac{1}{(1 + r)^{t_1}} \left[\frac{1}{r} - \frac{e^{m(t_1-1)}}{1 - e^{-m}(1 + r)^{-1}}\right].$$

Assuming nB and $-\epsilon_{h_0}$ are independent, $Cov(nB, -\epsilon_{h_0}) = 0$. The standard error for $-\epsilon_{h_0}$ is calculated as;

$$\sigma_{\epsilon_{h_0}} = [h_0 e^{-mt_1}/(1 - e^{-m})]^2 Var(q_A)(adj)$$

where $Var(q_A) = (4.07 \times 10^{-7})^2 = 1.657 \times 10^{-13}$ and (adj) is an adjustment factor which allows the interpretation of the elasticity in terms of weight of a fish rather than the number of fish (see Section 2) and has the value of 5.3. The standard error of $-\epsilon_{h_0}$ is calculated to be 0.1803. The standard error of nB is calculated as part of the SHAZAM output as 19,905, therefore $Var(nB)$ is 3.962×10^8. The value of the constant term a is calculated as 312.905. The standard error of $PV(nB(T)$ is therefore;

$$[(312.905)(3.962 \times 10^8)(0.0325)]^{1/2} = 6{,}228{,}370.$$

(ii) Test for difference between MB and MC$_i$S:

Tests for the significance of the difference between the estimates of marginal cost to the purse seine fleet and marginal benefit to the longline fleet were carried out according to the following null and alternative hypotheses:

$$H_0: \mu_{MB} - \mu_{MC_i} = 0$$

against
$$H_1: \mu_{MB} - \mu_{MC_i} > 0 \text{ for } i = 1, 2$$

and where μ_{MB} is the true marginal benefit and μ_{MC_i} is the true marginal cost of the yellowfin conservation policy. The test statistic is:

$$t = \frac{\hat{\mu}_{MB} - \hat{\mu}_{MC_i}}{\hat{\sigma}_{MB-MC_i}},$$

where $\hat{\sigma}_{MB-MC_i} = \hat{\sigma}\sqrt{(1)/(n_{MB}) + (1)/(n_{MC_i})}$ and with $(n_{MB} + n_{MC_i} - 2)$ degrees of freedom. Under the assumption that the variances of the two populations from which the purse seine and longline samples were taken are equal, the pooled estimate of the standard error is calculated as:

$$\hat{\sigma} = \sqrt{\frac{(n_{MB} - 1)\sigma^2_{MB} + (n_{MC_i} - 1)\sigma^2_{MC_i}}{n_{MB} + n_{MC_i} - 2}}$$

Let $i = 1$ for the targeting and $i = 2$ for the non-targeting scenarios for the marginal cost estimate for the purse seine fleets. Both tests are performed at the 5% level of significance for which the critical value for the t-test is 1.645 for a one-tail test and degrees of freedom > 120. The test statistics are calculated from the following values of the point estimates and numbers of observations:

$$\begin{array}{llllll}
\hat{\mu}_{MB} = & 3{,}472{,}748 & n_{MB} = & 3{,}610 & \hat{\sigma}_{MB} = & 6{,}228{,}370 \\
\hat{\mu}_{MC_1} = & 115{,}230 & n_{MC_1} = & 131 & \hat{\sigma}_{MC_1} = & 108{,}250 \\
\hat{\mu}_{MC_2} = & 367{,}670 & n_{MC_2} = & 131 & \hat{\sigma}_{MC_2} = & 58{,}918.
\end{array}$$

The test statistic for the test of MB > MC_1 is t = 6.169; therefore reject the null hypothesis at the 5% level. The test statistic for the test MB > MC_2 is t = 5.705; therefore reject the null hypothesis at the 5% level of significance also.